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STRIP CASTING APPARATUS

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Invention Title:

STRIP CASTING APPARATUS

The following statement is a full description of this invention, including the best method of performing it known to me/us:

STRIP CASTING APPARATUS

TECHNICAL FIELD

This invention relates to the casting of metal strip. It has particular but not exclusive application to the casting of ferrous metal strip.

It is known to cast metal strip by continuous casting in a twin roll caster. Molten metal is introduced between a pair of contra-rotated horizontal casting rolls which are cooled so that metal shells solidify on the moving roll surfaces and are brought together at the nip between them to produce a solidified strip product delivered downwardly from the nip between the rolls. The term "nip" is used herein to refer to the general region at which the rolls are closest together. The molten metal may be poured from a ladle into a smaller vessel or series of smaller vessels from which it flows through a metal delivery nozzle located above the nip so as to direct it into the nip between the rolls, so forming a casting pool of molten metal supported on the casting surfaces of the rolls immediately above the nip. This casting pool may be confined between side plates or dams held in sliding engagement with the ends of the rolls.

Although twin roll casting has been applied with some success to non-ferrous metals which solidify rapidly on cooling, there have been problems in applying the technique to the casting of ferrous metals which have high solidification temperatures and tend to produce defects caused by uneven solidification at the chilled casting surfaces of the rolls. One particular problem arises due to the formation of pieces of solid metal known as "skulls" in the vicinity of the pool confining side plates. These problems are exacerbated when efforts are made to reduce the superheat of the incoming molten metal. The rate of heat loss from the melt pool is greatest near the side plates due primarily to additional conductive heat transfer through the side plates to the roll ends. This high rate

of local heat loss is reflected in the tendency to form "skulls" of solid metal in this region which can grow to a considerable size and fall between the rolls causing defects in the strip generally known as "snake eggs". It is therefore very important to maintain constant pool conditions in the region of the side plates. In particular, the setting of the gaps between the nozzle ends and the inner faces of the side plates is critically important.

We have determined that significant flow changes are brought about by variation in the position in the ends of the delivery nozzle relative to the side plates which may be brought about by inaccurate location of the delivery nozzle during set up and by subsequent movement of the nozzle ends due to thermal expansion during casting and inward movement of the side plates due to ware of those plates. This problem remains even if the nozzle is designed specifically to provide an increased flow of metal to the "triple point" regions (*ie.* where the side plates and casting rolls meet in the meniscus regions of the casting pool) to increase the heat input to these regions of the pool. Examples of such nozzles may be seen in United States Patents 4,694,887, 5,221,511 and our earlier Australian Patent Application 35218/97 based on Provisional Application PO2367.

Although triple point pouring has been effective to reduce the formation of skulls in the triple point regions of the pool it has not been possible completely to eliminate the problem because the generation of defects is remarkably sensitive to even minor variations in the flow of metal into the triple point regions of the pool and movements of the nozzle ends due to thermal expansion during casting can be sufficient to cause defects. As the gap between the nozzle end and the side plate is reduced the downwardly inclined flow of metal from the triple point pouring passages in the ends of the nozzle impinges higher on the side plates and away from the triple point region.

This can lead to the formation of skulls with subsequent snake egg defects or in extreme cases can cause the poured metal to surge upwardly in the reduced gap between the nozzle ends and side plates to spill over the upper edges of the side plates. The present invention provides an improvement by which it is possible to maintain substantially constant spacing between the nozzle ends and the side plates throughout casting.

DISCLOSURE OF THE INVENTION

According to the invention there is provided apparatus for casting metal strip including

a pair of parallel casting rolls forming a nip between them,

an elongate metal delivery nozzle formed in a plurality of discrete elongate pieces disposed end to end,

nozzle support means supporting the nozzle pieces such that the nozzle extends above and along the nip between the casting rolls for delivery of molten metal into the nip whereby to form a casting pool of molten metal supported above the nip,

a pair of pool confinement plates at the ends of the nip,

plate biasing means to bias the pool confinement plates against end surfaces of the rolls so that the plates move inwardly of the rolls to accommodate wear of the plates, and

nozzle end shifter means to shift the nozzle pieces defining the outer nozzle ends on the support means with inward movements matching the inward movements of said side plates accommodating wear of the side plates thereby to maintain substantially constant spacings between the side plates and the nozzle ends.

The side plates may engage end surfaces of both rolls at each end of the nip.

Alternatively, the rolls may be staggered longitudinally relative to one another and each side plate

may engage an end surface of one of the rolls and a circumferential surface of the other.

The nozzle end shifter means may comprise spacers disposed between the nozzle ends and the side plates to set the spacings between the nozzle ends and the side plates and through which the side plates push the nozzle ends inwardly as they move inwardly under the influence of the biasing means to accommodate wear of the side plates.

The spacers may be carried by the nozzle ends to engage the side plates or they may be carried by the side plates to engage the nozzle ends.

The side plates may be held in a pair of side plate holders and the biasing means may operate on those holders. In that case the nozzle end shifter means may alternatively comprise pusher elements extending between the side plate holders and the nozzle ends. Such pusher elements may be in the form of rods extending through apertures in the side plates.

The nozzle pieces may comprise upwardly opening elongate troughs to receive discrete streams of molten metal from a distributor, trough outlet means to deliver molten metal from the trough into the casting pool, and outer end formations defining reservoirs for molten metal at the two ends of the nozzle which each receive discrete streams of molten metal from the distributor and supply that molten metal to said metal outlet passages at the ends of the nozzle.

The invention also extends to a refractory nozzle for delivery of molten metal to a casting pool of a twin roll caster, said nozzle comprising a plurality of elongate nozzle pieces disposable end to end to define the nozzle, said nozzle pieces being formed with respective upwardly opening elongate troughs, trough outlet means to deliver molten metal from the trough outwardly from the nozzle, outer end formations defining reservoirs for molten metal at the two ends of the nozzle, flow passages extending from said reservoirs to direct molten metal from the reservoirs

in streams directed downwardly from the nozzle end formations, and discrete localised projections projecting longitudinally outwardly from the end faces of the nozzle.

Preferably, said projections are disposed on vertical centre lines of the nozzle ends.

Preferably, the nozzle pieces are formed with laterally outwardly projecting side flanges by means of which they can be mounted on nozzle supports.

Preferably further, each of said reservoirs is separated from the respective nozzle trough by a wall over which molten metal can flow into the trough from the reservoir when the reservoir is full.

BRIEF DESCRIPTION OF THE DRAWINGS

In order that the invention may be more fully explained one particular method and apparatus will be described in some detail with reference to the accompanying drawings in which:

Figure 1 illustrates a twin-roll continuous strip caster constructed and operating in accordance with the present invention;

Figure 2 is a vertical cross-section through important components of the caster illustrated in Figure 1 including a metal delivery nozzle constructed in accordance with the invention;

Figure 3 is a further vertical cross-section through important components of the caster taken transverse to the section of Figure 2;

Figure 4 is a diagrammatic plan view of the metal delivery nozzle and essential components of the caster embodying the invention;

Figure 4A illustrates one of the nozzle support brackets;

Figure 5 is a side elevation of a one half segment of the metal delivery nozzle;

Figure 6 is a plan view of the nozzle segment shown in Figure 5;

Figure 7 is a longitudinal cross-section through the delivery nozzle segment;

Figure 8 is a perspective view of the delivery nozzle segment;

Figure 9 is an inverted perspective view of the nozzle segment;

Figure 10 is a transverse cross-section through the delivery nozzle segment on the line 10-10 in Figure 5;

Figure 11 is a cross-section on the line 11-11 in Figure 7; and

Figure 12 is a cross-section on the line 12-12 in Figure 7.

Figure 13 illustrates a modified form of caster also in accordance with the invention;

Figure 14 illustrates a further modification also in accordance with the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The illustrated caster comprises a main machine frame 11 which stands up from the factory floor 12. Frame 11 supports a casting roll carriage 13 which is horizontally movable between an assembly station 14 and a casting station 15. Carriage 13 carries a pair of parallel casting rolls 16 to which molten metal is supplied during a casting operation via a distributor 18 and delivery nozzle 19. Casting rolls 16 are water cooled so that shells solidify on the moving roll surfaces and are brought together at the nip between them to produce a solidified strip product 20 at the nip outlet. This product is fed to a standard coiler 21 and may subsequently be transferred to a second coiler 22.

Roll carriage 13 comprises a carriage frame 31 mounted by wheels 32 on rails 33 extending along part of the main machine frame 11 whereby roll carriage 13 as a whole is mounted for movement along the rails 33. Carriage frame 31 carries a pair of roll cradles (not shown) in which the rolls 16 are rotatably mounted. Carriage 13 is

movable along the rails 33 by actuation of a double acting hydraulic piston and cylinder unit 39, connected between a drive bracket 40 on the roll carriage and the main machine frame so as to be actuable to move the roll carriage between the assembly station 14 and casting station 15 and visa versa.

Casting rolls 16 are contra rotated through drive shafts 41 from an electric motor and transmission mounted on carriage frame 31. Rolls 16 have copper peripheral walls formed with a series of longitudinally extending and circumferentially spaced water cooling passages supplied with cooling water through the roll ends from water supply ducts in the roll drive shafts 41 which are connected to water supply hoses 42 through rotary glands 43. The rolls may typically be about 500 mm diameter and up to 2 m long in order to produce up to 2 m wide strip product.

Distributor 18 is formed as a wide dish made of a refractory material such as high alumina castable with a sacrificial lining. One side of the distributor receives molten metal from a ladle. The other side of the distributor is provided with a series of longitudinally spaced metal outlet openings 52. The lower part of the distributor carries mounting brackets 53 for mounting the distributor onto the roll carriage frame 31 and provided with apertures to receive indexing pegs 54 on the carriage frame so as accurately to locate the distributor.

Delivery nozzle 19 is formed by two discrete elongate pieces 19A supported on the roll carriage frame by stainless steel mounting brackets 60. Nozzle pieces 19A are formed as identical nozzle half segments made of a refractory material such as alumina graphite. Each of these nozzle pieces is mounted by two pairs of the brackets 60 in the manner shown in Figure 4 with a pair of brackets supporting each end of the nozzle piece. The pieces are supported so as to be disposed in end to end relationship with a gap 50 between them. The upper parts of the nozzle pieces are formed with outwardly projecting side flanges 55

which locate on the mounting brackets. The outer edges of side flanges 55 are upwardly and outwardly tapered and engage complementary inclined inner faces 60A on the brackets 60 to locate the nozzle pieces 19A against lateral movement.

The construction of the nozzle pieces 19A is illustrated in Figures 5 to 12. Each nozzle piece is of generally trough formation so that the nozzle 19 defines an upwardly opening inlet trough 61 to receive molten metal flowing downwardly from the openings 52 of the distributor. Trough 61 is formed between nozzle side walls 62 and end walls 70 and may be considered to be transversely partitioned between its ends by the two flat end walls 80 of the nozzle pieces 19A which are spaced apart to form the gap 50. The bottom of the trough is closed by a horizontal bottom floor 63 which meets ~~the trough~~ side walls 62 at chamfered bottom corners 81. The nozzle is provided at these bottom corners with a series of side openings in the form of longitudinally spaced elongate slots 64 arranged at regular longitudinal spacing along the nozzle. Slots 64 are positioned to provide for egress of molten metal from the trough at the level of the trough floor 63. The trough floor is provided adjacent the slots with recesses 83 which slope outwardly and downwardly from the centre of the floor toward the slots and the slots continue as extensions of the recesses 83 to slot outlets 64 disposed in the chamfered bottom corners 81 of the nozzle beneath the level of the upper floor surface 85.

The outer ends of the nozzle segments are provided with triple point pouring end formations denoted generally as 87 extending outwardly beyond the nozzle end wall 70. Each end formation 87 defines a small open topped reservoir 88 to receive molten metal from the distributor, this reservoir being separated from the main trough of the nozzle by the end wall 70. The upper end 89 of end wall 70 is lower than the upper edges of the trough and the outer parts of the reservoir 88 and can serve as a weir to allow

back flow of molten metal into the main nozzle trough from the reservoir 88 if the reservoir is over filled, as will be more fully explained below.

Reservoir 88 is shaped as a shallow dish having a flat floor 91, inner and side faces 92, 93 and a curved upright outer face 94. Although side faces 92, 93 are shown as inclined to the vertical they may be formed to stand straight up from the floor 91 so as to be essentially vertical. A pair of triple-point pouring passages 95 extend laterally outwardly from reservoir 88 just above the level of the floor 91 to connect with triple point pouring outlets 96 in the undersides of the nozzle end formations 87, the outlets 96 being angled downwardly and inwardly to deliver molten metal into the triple point regions of the casting pool.

Molten metal falls from the outlet openings 52 of the distributor in a series of free-falling vertical streams 65 into the bottom part of the nozzle trough 61. Molten metal flows from this reservoir out through the side openings 64 to form a casting pool 68 supported above the nip 69 between the casting rolls 16. The casting pool is confined at the ends of rolls 16 by a pair of side closure plates 56 which are held against the ends 57 of the rolls. Side closure plates 56 are made of strong refractory material, for example boron nitride. They are mounted in plate holders 72 which are movable by actuation of a pair of hydraulic cylinder units 73 to bring the side plates into engagement with the ends of the casting rolls to form end closures for the casting pool of molten metal. Hydraulic cylinder units 73 serve to bias the plates 56 against the roll ends throughout the casting and to move the plates inwardly to accommodate wear. Plate holders 72 are connected to hydraulic cylinder units 73 by pivot connections 74 which permit rocking movements of the plates for self-adjustment with the ends of the rolls.

In the casting operation the flow of metal is controlled to maintain the casting pool at a level such

that the lower end of the delivery nozzle 19 is submerged in the casting pool and the two series of horizontally spaced side openings 64 of the delivery nozzle are disposed immediately beneath the surface of the casting pool. The molten metal flows through the openings 64 in laterally outwardly directed jet streams from both sides of the nozzle in the general vicinity of the casting pool surface so as to impinge on the cooling surfaces of the rolls in the immediate vicinity of the pool surface. This maximises the temperature of the molten metal delivered to the meniscus regions of the pool and it has been found that this significantly reduces the formation of cracks and meniscus marks on the melting strip surface.

Molten metal is caused to flow from the extreme bottom part of the nozzle trough 61 through the nozzle side openings 64 generally at the level of the floor of the trough. The metal enters the casting pool in mutually oppositely directed jet streams immediately below the surface of the pool to impinge on the casting roll surfaces in the meniscus regions of the pool.

It is important to note that nozzle side slots 64 are provided at the inner ends of the two nozzle sections. This ensures adequate delivery of molten metal to the pool in the vicinity of the central partition in the nozzle and avoids the formation of skulls in this region of the pool.

The triple point pouring reservoirs 88 receive molten metal from the two outermost streams 65 falling from the distributor 18. The alignment of the two outermost holes 52 in the distributor is such that each reservoir 88 receives a single stream impinging in the centre of the flat floor 91. The impingement of the molten metal on floor 91 causes the metal to fan outwardly across the floor and outwardly through the triple point pouring passages 95 to the outlets 96 which produce downwardly and inwardly inclined jets of hot metal directed across the faces of the side dams and along the edges of the casting rolls toward the nip. Triple point pouring proceeds with only a shallow

and wide pool of molten metal within each of the reservoirs 88, the height of this pool being limited by the height of the upper end 89 of the wall 70. When reservoir 88 is filled molten metal can flow back over the wall end 89 into the main nozzle trough so that the wall end serves as a weir to control the depth of the metal pool in the triple point pouring supply reservoir 88. The depth of the pool is more than sufficient to supply the triple point pouring passages so as to maintain flow at a constant head whereby to achieve a very even flow of hot metal through the triple point pouring passages. This control flow is most important to proper formation of the edge parts of the strip. Excessive flow through the triple point passages can lead to bulging in the edges of the strip whereas too little flow will produce skulls and "snake egg" defects in the strip.

During casting the core nozzle pieces 19A undergo very significant thermal expansion through contact with the molten steel at temperatures of the order of 1600°C or more. In a typical installation each nozzle piece 19A may for example be about 650cm long and the thermal expansion may produce a change in length of up to 12mm. The gap between the core nozzle ends and the side dams will usually be of the order of 15mm to produce effective triple point pouring of molten metal across the side dams. Accordingly the thermal expansion of the nozzle is very significant and without the aid of the present invention can lead to a severe reduction in the gap between the nozzle ends and the side dams, causing the molten metal leaving the triple point pouring passages 95 to impinge on the upper parts of the side dams above the casting pool leading to the formation of skulls and in extreme cases spilling of metal over the upper edges of the side dams.

In accordance with the present invention the two outer ends of the nozzle pieces 19A are provided with discrete projections 71 to engage the inner faces of the pool confinement plates 56 when those plates are brought

the upper parts of the side plates 56.

Figure 14 diagrammatically illustrates a further modification in which the casting rolls 16′ are staggered longitudinally relative to one another and each of the side plates 56′ engage an end surface of one of the rolls 16′ and a circumferential surface of the other roll 16′.

The illustrated forms of apparatus have been advanced by way of example only and the invention is not limited to the details illustrated. For example, instead of being formed or mounted on the ends of the nozzle, the projections or spacers 71 could be formed or mounted on the side plates 56. Specifically, the projections could be provided by bosses or barrel pieces mounted in holes in the inner faces of the side dams.

Although a two piece nozzle has been illustrated it would be possible, particularly for the casting of wider strips, to provide a three piece nozzle with a fixed central piece and two end pieces spaced one to either end of the central piece.

It is not essential that the nozzle trough be provided with side openings of the kind shown in the illustrated apparatus, although that is the presently preferred form of nozzle. The invention may be applied to any form of nozzle providing for pouring of molten metal from its ends.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. Apparatus for casting metal strip including

a pair of parallel casting rolls forming a nip between them,

an elongate metal delivery nozzle formed in a plurality of discrete elongate pieces disposed end to end,

nozzle support means supporting the nozzle pieces such that the nozzle extends above and along the nip between the casting rolls for delivery of molten metal into the nip whereby to form a casting pool of molten metal supported above the nip,

a pair of pool confinement plates at the ends of the nip,

plate biasing means to bias the pool confinement plates against end surfaces of the rolls so that the plates ~~move~~ inwardly of the rolls to accommodate wear of the plates, and

nozzle end shifter means to shift the nozzle pieces defining the outer nozzle ends on the support means with inward movements matching the inward movements of said side plates accommodating wear of the side plates thereby to maintain substantially constant spacings between the side plates and the nozzle ends.

2. Apparatus as claimed in claim 1, wherein the side plates engage end surfaces of both rolls at each end of the nip.

3. Apparatus as claimed in claim 1, wherein the rolls are staggered longitudinally relative to one another and each side plate engages an end surface of one of the rolls and a circumferential surface of the other.

4. Apparatus as claimed in any one of the preceding claims, wherein the nozzle end shifter means comprises spacers disposed between the nozzle ends and the side plates to set the spacings between the nozzle ends and the side plates and through which the side plates push the nozzle ends inwardly as they move inwardly under the influence of the biasing means to accommodate wear of the

side plates.

5. Apparatus as claimed in claim 4, wherein the spacers are carried by the nozzle ends to engage the side plates.

6. Apparatus as claimed in claim 4, wherein the spacers are carried by the side plates to engage the nozzle ends.

7. Apparatus as claimed in any one of the preceding claims, wherein the side plates are held in a pair of side plate holders and the biasing means operates on those holders.

8. Apparatus as claimed in claim 1, wherein the side plates are held in a pair of side plate holders, the biasing means operates on those holders, and the nozzle end shifter means comprises pusher elements extending between the side plate holders and the nozzle ends.

9. Apparatus as claimed in claim 8, wherein the pusher elements are in the form of rods extending through apertures in the side plates.

10. Apparatus as claimed in any one of the preceding claims, wherein the nozzle pieces comprise upwardly opening elongate troughs to receive discrete streams of molten metal from a distributor, trough outlet means to deliver molten metal from the trough into the casting pool, and outer end formations defining reservoirs for molten metal at the two ends of the nozzle which each receive discrete streams of molten metal from the distributor and supply that molten metal to metal outlet passages at the ends of the nozzle.

11. A refractory nozzle for delivery of molten metal to a casting pool of a twin roll caster, said nozzle comprising a plurality of elongate nozzle pieces disposable end to end to define the nozzle, said nozzle pieces being formed with respective upwardly opening elongate troughs, trough outlet means to deliver molten metal from the trough outwardly from the nozzle, outer end formations defining reservoirs for molten metal at the two ends of the nozzle,

flow passages extending from said reservoirs to direct molten metal from the reservoirs in streams directed downwardly from the nozzle end formations, and discrete localised projections projecting longitudinally outwardly from the end faces of the nozzle.

12. A refractory nozzle as claimed in claim 11, wherein said projections are disposed on vertical centre lines of the nozzle ends.

13. A refractory nozzle as claimed in claim 11 or claim 12, wherein the nozzle pieces are formed with laterally outwardly projecting side flanges by means of which they can be mounted on nozzle supports.

14. A refractory nozzle as claimed in any one of claims 11 to 13, wherein each of said reservoirs is separated from the respective nozzle trough by a wall over which molten metal can flow into the trough from the reservoir when the reservoir is full.

Dated this 7th day of December 1999

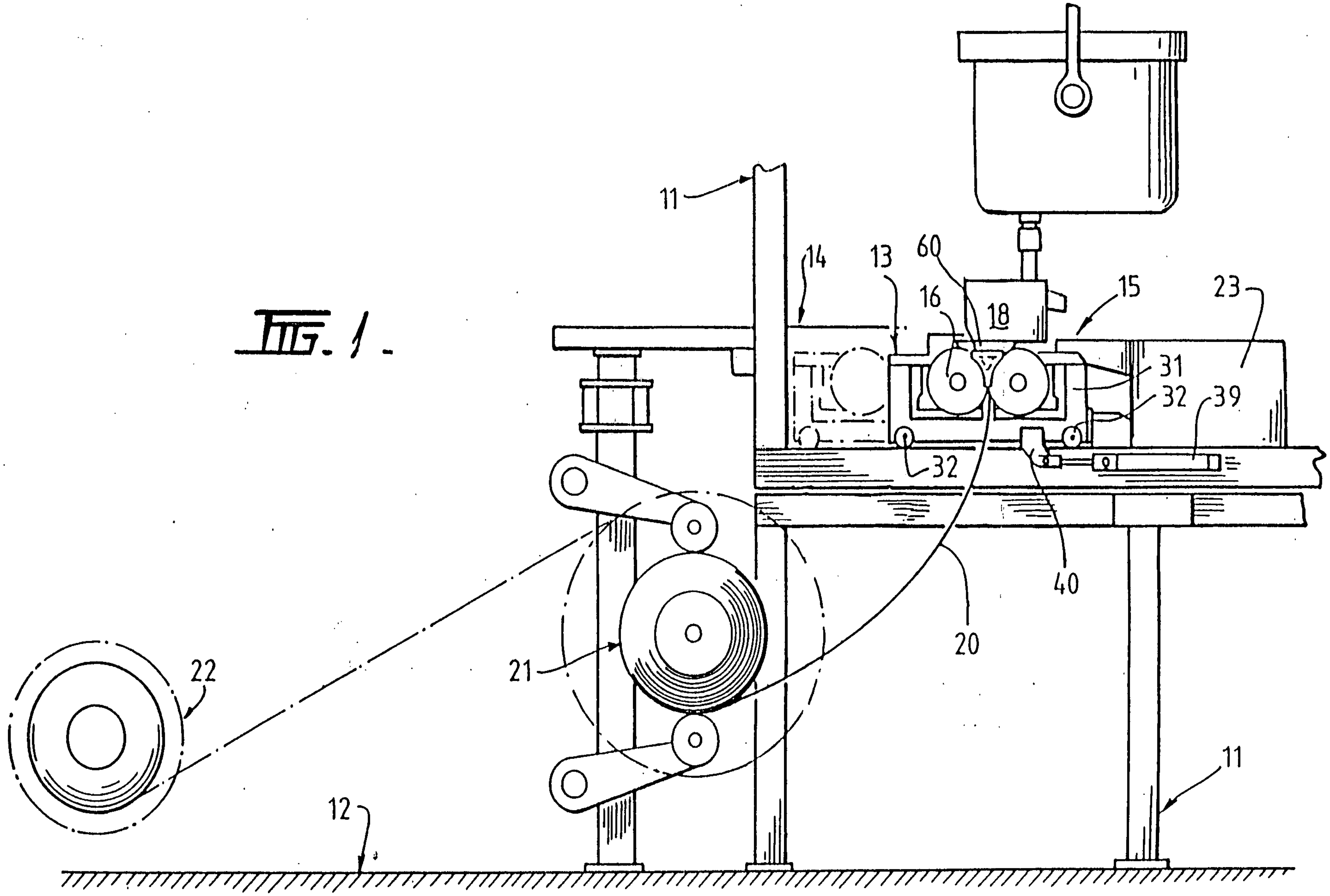
ISHIKAWAJIMA-HARIMA HEAVY INDUSTRIES COMPANY LIMITED and BHP STEEL (JLA) PTY LTD

By their Patent Attorneys

GRIFFITH HACK

Fellows Institute of Patent and Trade Mark Attorneys of Australia

FIG. 1.



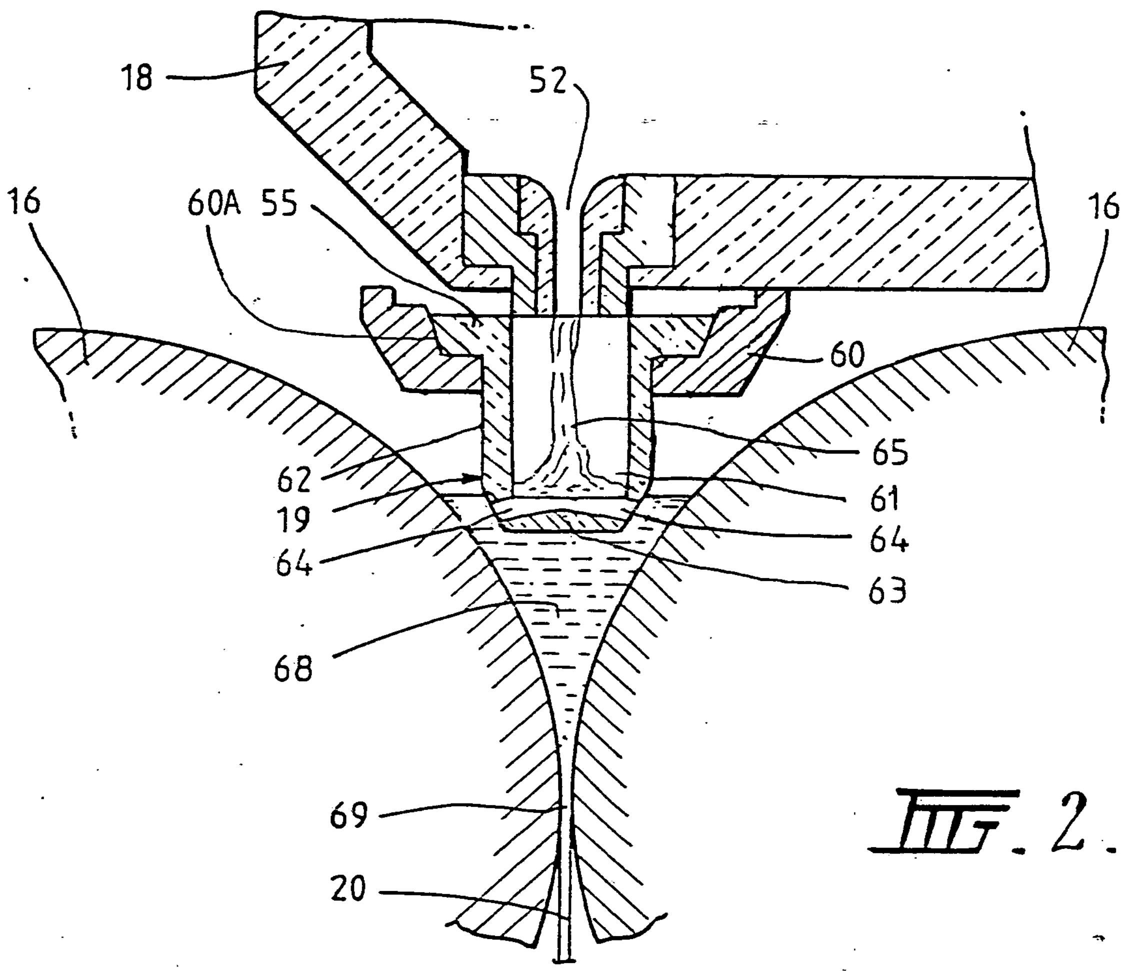
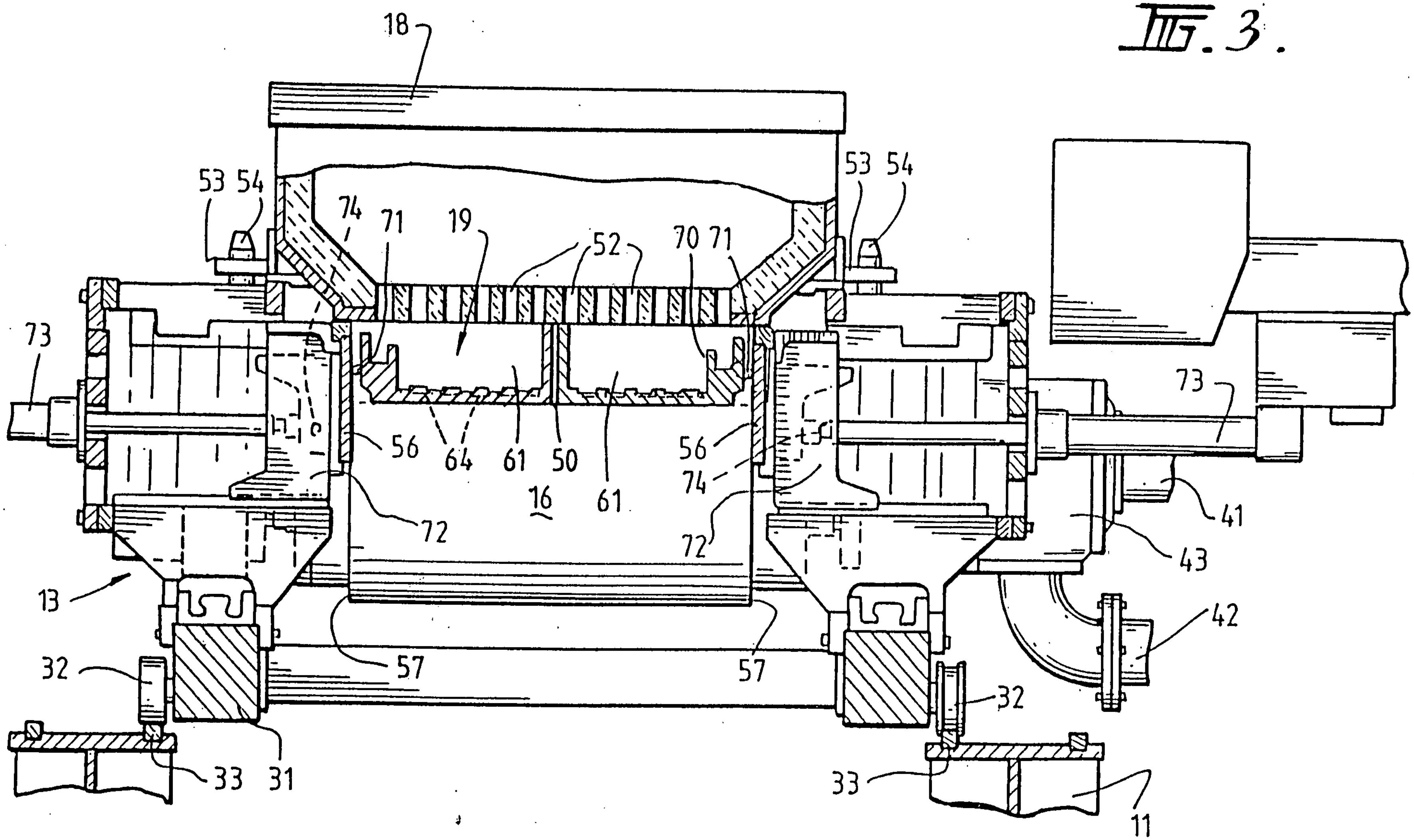


FIG. 2.

FIG. 3.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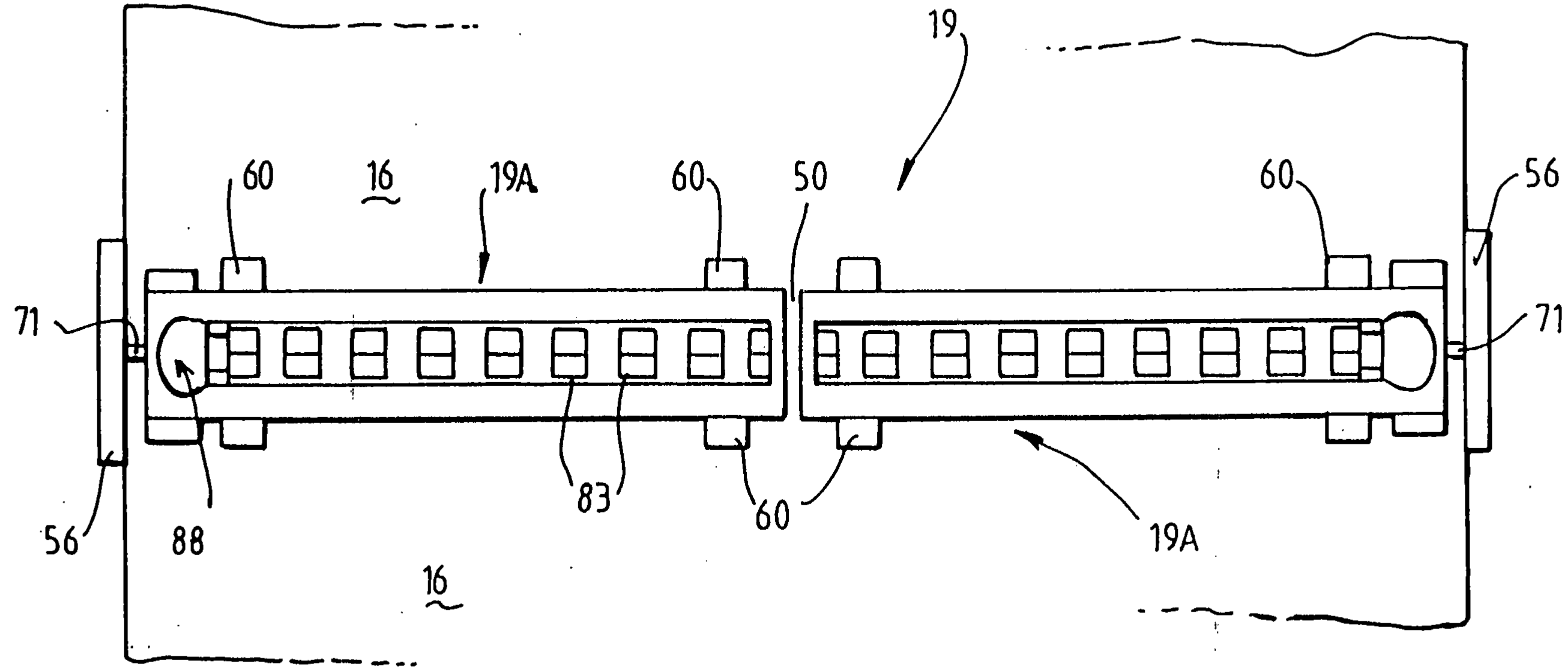

FIG. 4.

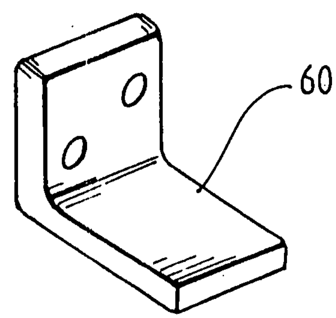

FIG. 4A.

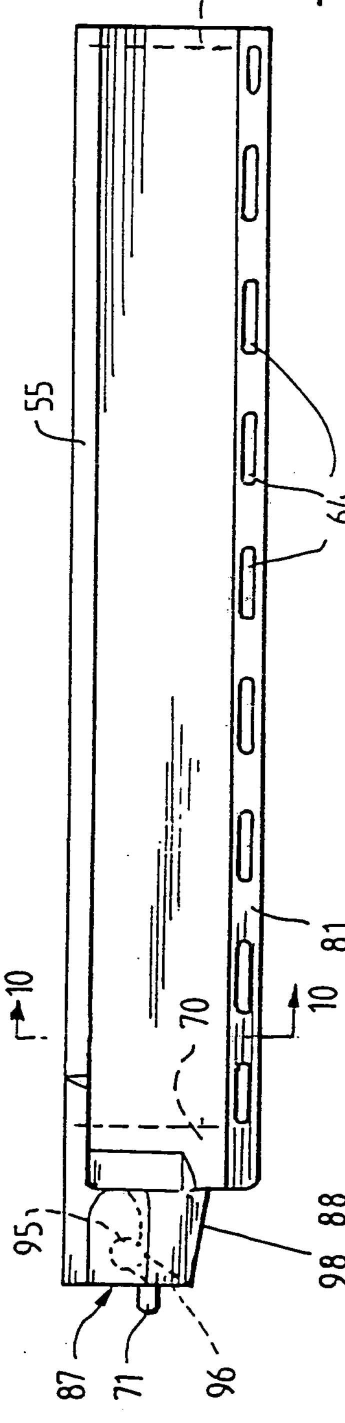

FIG. 5.

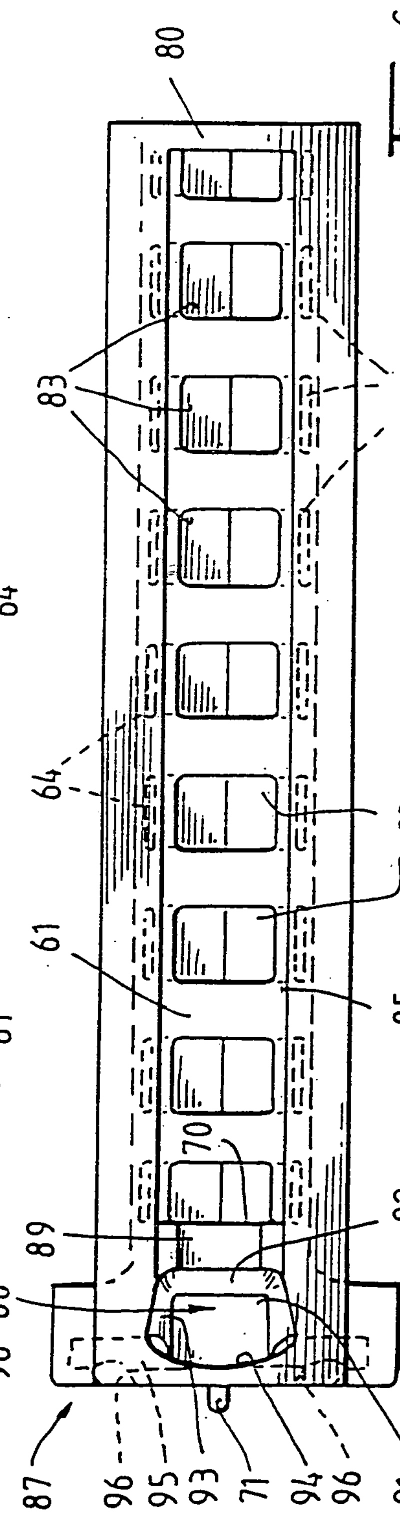

FIG. 6.

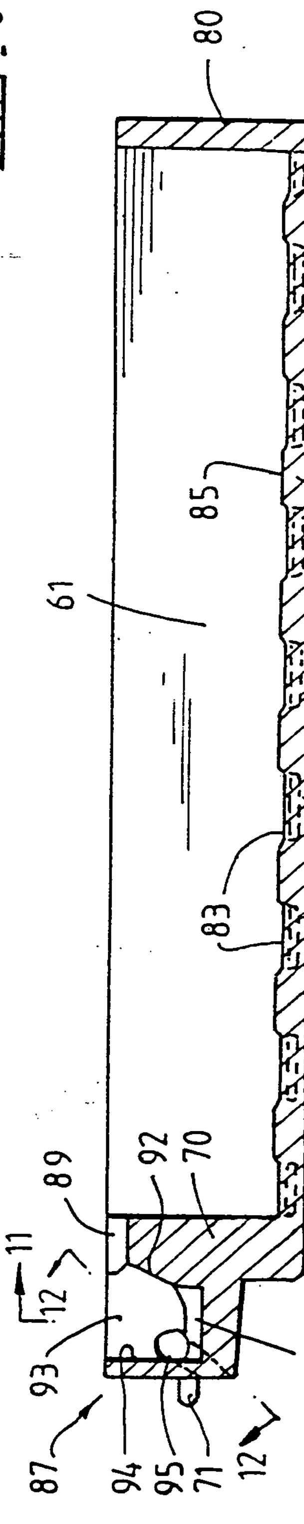

FIG. 7.

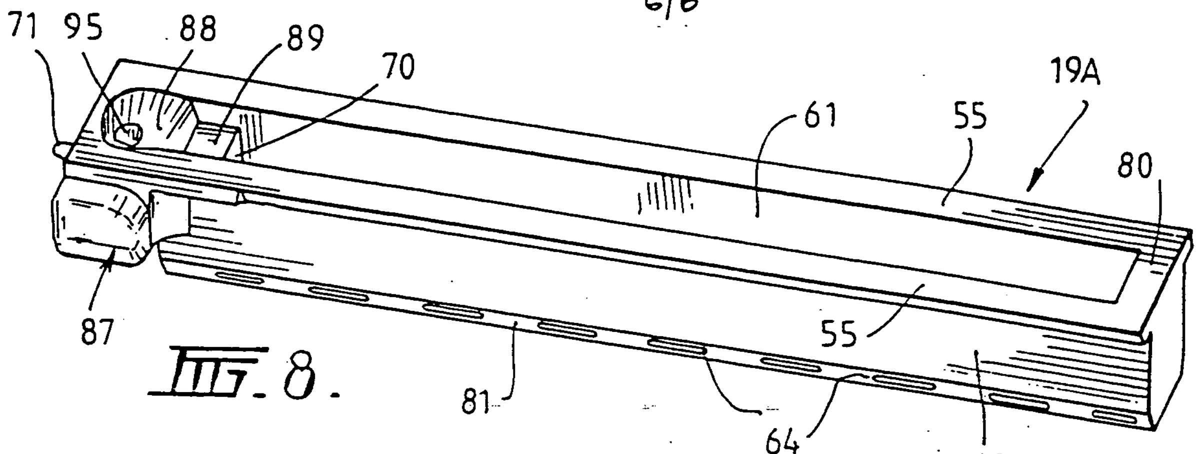

FIG. 8.

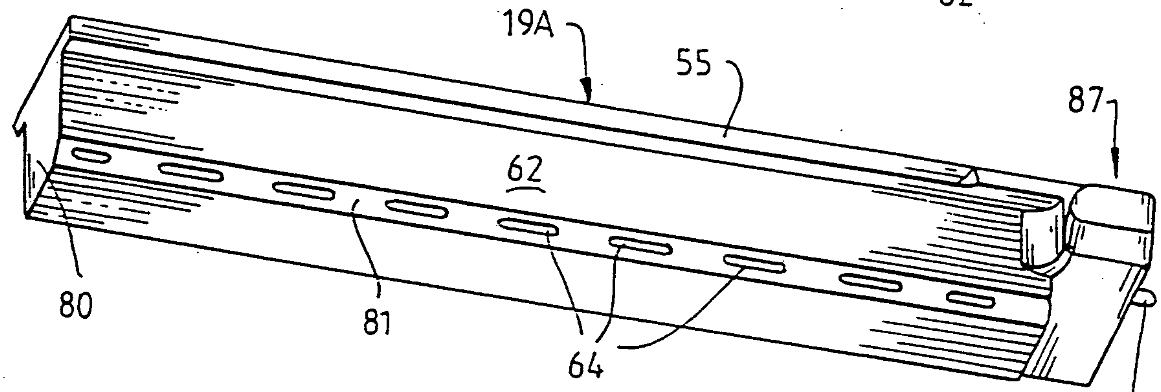

FIG. 9.

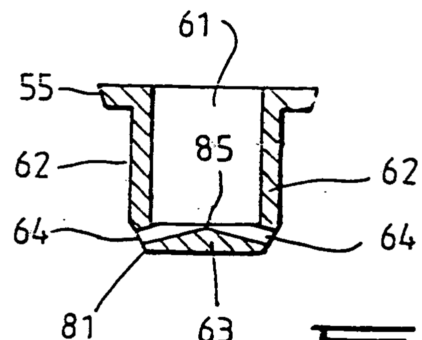

FIG. 10.

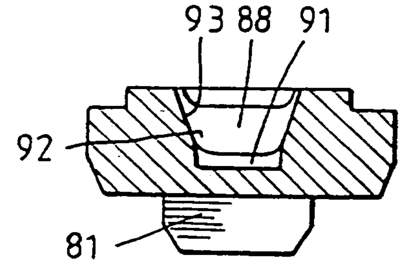

FIG. 11.

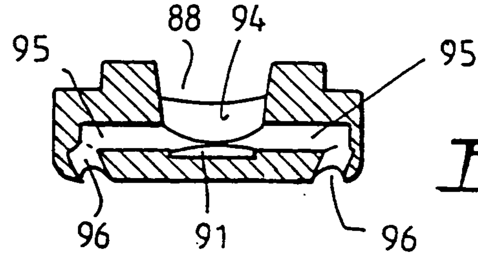

FIG. 12.

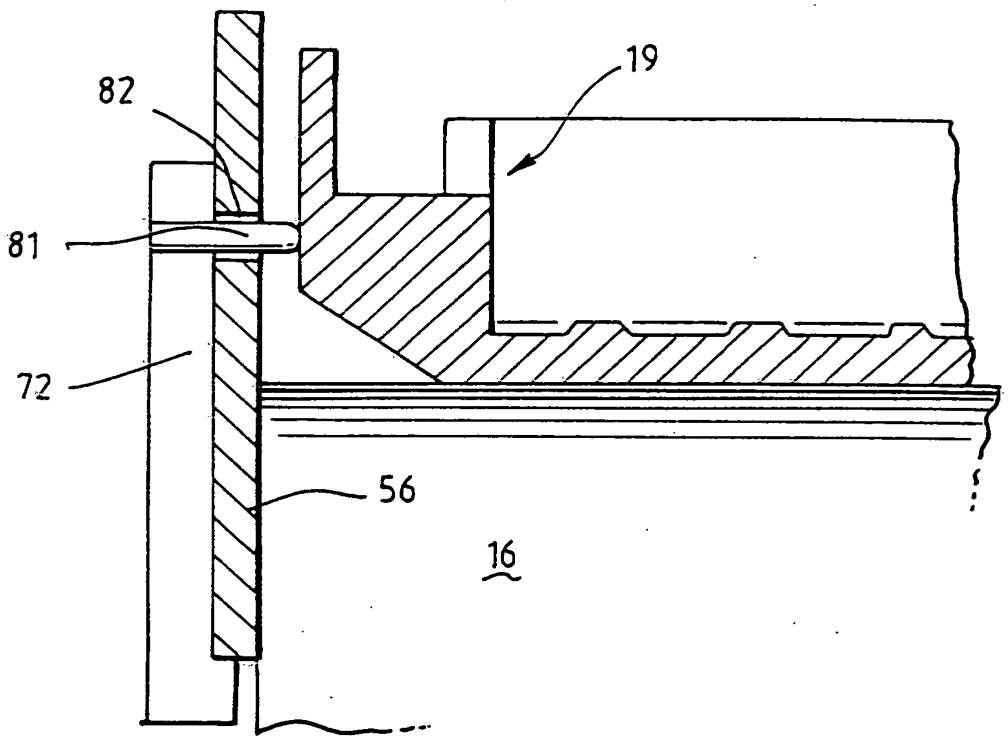

FIG. 13.

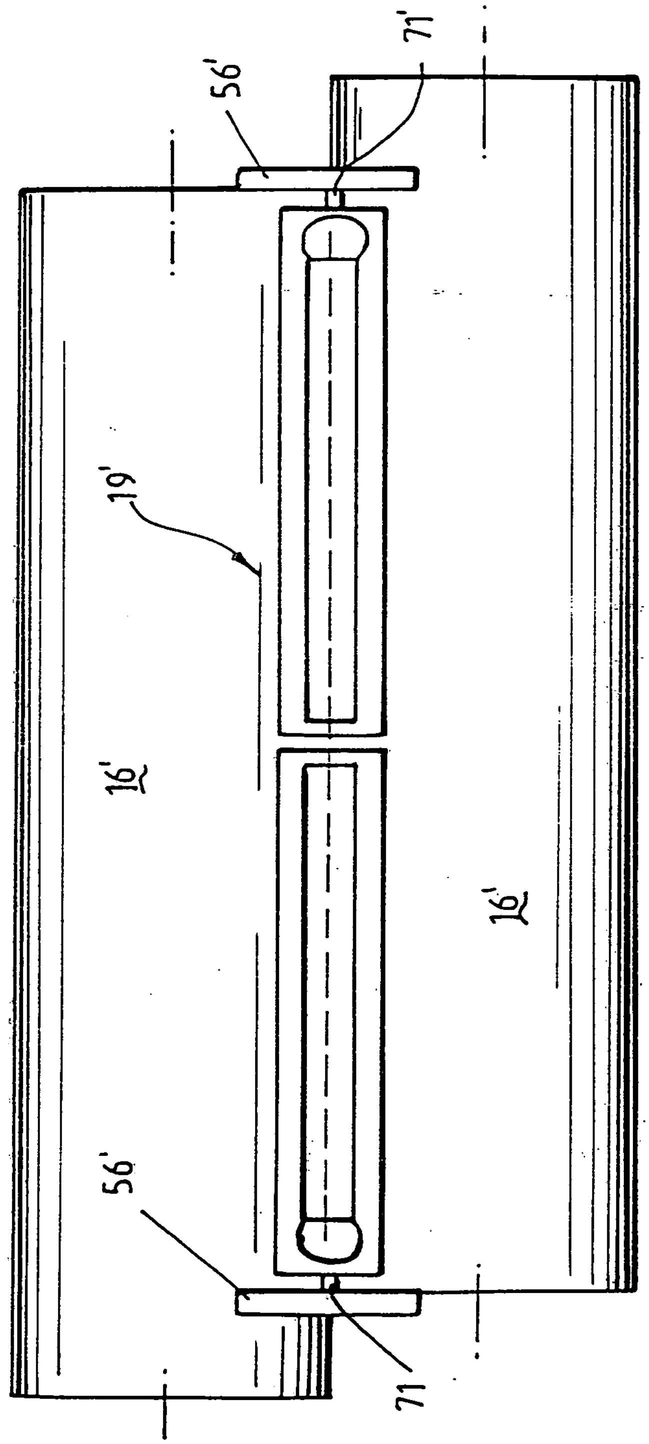

FIG. 14.